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TECHNICAL MEMORANDUM

X-189

EFFECT OF VERTICAL-TAIL AND RUDDER DEFLECTION

ON THE AERODYNAMIC CHARACTERISTICS OF A HYPERSONIC GLIDER

MODEL AT MACH NUMBERS OF ABOUT 0.62 AND 0.93

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TECHNICAL MEMORANDUM X-189

EFFECT OF VERTICAL-TAIL AND RUDDER DEFLECTION ON THE AERODYNAMIC CHARACTERISTICS OF A HYPERSONIC GLIDER MODEL AT MACH NUMBERS OF ABOUT 0.62 AND 0.93*

By F. E. West, Jr., Charles D. Trescot, Jr., and Alfred N. Wiley, Jr.

SUMMARY

A wind-tunnel investigation has been made to study the effects of vertical tail (at Mach numbers of about 0.62 and 0.93) and rudder deflection (at a Mach number of 0.94) on the aerodynamic characteristics of a hypersonic glider model. The model had a highly swept clipped-tip low triangular wing. It was tested with and without upper surface wing-tip vertical tails and with various deflections of single split-type rudders which were mounted on the tail outer surfaces. Vertical-tail deflection was varied from 8.1° toe-in to a maximum 5.0° toe-out and outward rudder deflection was varied from 0° to 21.1° at a tail deflection of about 0°. Tests were made at angles of attack from about -2° to 19° and at angles of sideslip of 0° and about 5°. Reynolds number, based on the mean aerodynamic chord, was about 2.75×10^6 at both Mach numbers.

Adding the vertical tails to the model caused increases in both the linearity and the slope of the normal-force curves. Changing the vertical-tail deflection from 8.1° toe-in to 5.0° toe-out at a Mach number of about 0.93 shifted the zero-lift pitching moment from a large negative value to a positive value and eliminated the pitchup tendency at moderate angles of attack. Although changing the vertical-tail deflection from 8.1° toe-in to about 0° at a Mach number of 0.62 decreased the negative zero-lift pitching moment, it did not eliminate the pitchup tendency. At a Mach number of 0.93 the model had a small amount of directional stability and generally positive effective dihedral. At a Mach number of 0.63 the model had essentially neutral directional stability and effective dihedral.

Rudder deflection had essentially no effect on rolling moment. Both yawing moment and side force varied almost linearly with rudder deflection. Angle of sideslip and angle of attack had very little effect on rudder effectiveness.

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INTRODUCTION

An investigation was made in the Langley transonic blowdown tunnel of the effect of vertical-tail and rudder deflection on the aerodynamic characteristics of a hypersonic glider model. Results of reference 1 showed that upper surface wing-tip-mounted vertical tails similar to those on the model of the present investigation had large effects on pitching moment. Hence, further study of vertical-tail configurations was considered desirable and also the determination of rudder effectiveness was desired.

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The results show the effects of adding vertical tails or deflection of the tails on the glider longitudinal stability characteristics at Mach numbers of about 0.62 and 0.93. Lateral stability derivatives are presented for the model at the same two Mach numbers. The effects of rudder deflection on the lateral characteristics at angles of sideslip of 0° and about 5° are also shown at a Mach number of about 0.94. Results are presented at angles of attack from about -2° to 19° for vertical-tail deflections from about 8° toe-in to 0° at a Mach number of 0.62 and to 5° toe-out at a Mach number of 0.93, and for rudder deflections from 0° to 21°. The results at a Mach number of 0.92 for the vertical-tail deflection of about 8° toe-in were obtained from reference 1.

SYMBOLS

The forces and moments are referenced to the body axes which have their origin on the body center line at 46 percent of the wing mean aerodynamic chord (64 percent of the body length).

A aspect ratio

b wing span

C_N normal-force coefficient, $\dfrac{\text{Normal force}}{q_\infty S}$

C_Y side-force coefficient, $\dfrac{\text{Side force}}{q_\infty S}$

ΔC_Y side-force coefficient due to rudder deflection

$C_{Y_\beta} = \dfrac{\partial C_Y}{\partial \beta}$ per degree

[redacted]

C_l rolling-moment coefficient, $\frac{\text{Rolling moment}}{q_\infty Sb}$

$C_{l_\beta} = \frac{\partial C_l}{\partial \beta}$ per degree

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{q_\infty S\bar{c}}$

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C_n yawing-moment coefficient, $\frac{\text{Yawing moment}}{q_\infty Sb}$

ΔC_n yawing-moment coefficient due to rudder deflection

$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$ per degree

$\bar{c}$ wing mean aerodynamic chord

i_v vertical-tail angle, positive when toed-in and negative when toed-out

M_∞ free-stream Mach number

q_∞ free-stream dynamic pressure

r radius

S total wing area

α angle of attack

β angle of sideslip

δ_r outward deflection of single split-type rudders, positive for right rudder and negative for left rudder

Subscripts:

L left

R right

[redacted]

MODEL AND APPARATUS

A drawing of the model (designated $B_1W_4V_1$ in ref. 1) including the single split-type rudders set at a nominal deflection is shown in figure 1. The rudders were mounted on the outer surfaces of the vertical tails and were only deflected outward. The model was also used in the investigation discussed in reference 1. Vertical-tail deflection was varied about the hinge lines (at 50.7 percent of the vertical-tail root chords) shown in figure 1. All parts of the model were made of steel.

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The model was mounted on an internal 5-component electrical-strain- 7
gage balance that was attached to the sting support system in the Langley 4
transonic blowdown tunnel. The sting had a diameter of 0.5 inch at the 6
model base and had a conical half angle of 0.7°. The tunnel has an octagonal slotted throat section measuring 26 inches between flats.

TESTS

Normal-force, pitching-moment, rolling-moment, yawing-moment, and side-force data were obtained for all configurations. Tests were made through an angle-of-attack range at angles of sideslip of either 0° or about 5°. Maximum angle-of-attack range was about -2° to 19°.

At a Mach number of about 0.93 and an angle of sideslip of 0° the model was investigated with the vertical tails at incidences of about -5° and 0° and with the tails off. Except for the tail incidence of -5°, similar configurations were also tested at a Mach number of about 0.62 and an angle of sideslip of 0°. For an angle of sideslip of about 5°, the tail-off configuration was tested at a Mach number of about 0.93 and the 0° tail-incidence configuration was tested at both Mach numbers.

Rudders were investigated on the model in various deflection combinations at angles of sideslip of 0° and about 5° for only a Mach number of about 0.94. These combinations which are indicated as $\delta_{r,L}$ and $\delta_{r,R}$, respectively, were 0° and 0°, -10.7° and 10.7°, 0° and 10.7°, -10.7° and 21.1°, and 0° and 21.1°.

Transition strips consisting of 0.001- to 0.002-inch carborundum grains spread on a thin wet coating of shellac were applied to the model surfaces. The grain size, which was selected after study of reference 2, was approximately the minimum size required to cause boundary-layer transition. The strips were about 1/16 inch in width and the grains covered 5 to 10 percent of the strip areas. These strips were put on the upper and lower surfaces of the wing, the side surfaces of the tails, and around

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the periphery of the body nose. Leading edges of the strips were located at 5 percent of the wing chord, 7.5 percent of the vertical-tail chord, and the line of tangency of the forebody cone and the sperical nose. The average Reynolds number based on the wing mean aerodynamic chord was about 2.75×10^6 at both Mach numbers.

PRECISION

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Estimated accuracy of the coefficients (based on balance accuracy), and other pertinent parameters are indicated below:

C_N	±0.01
C_m	±0.002
C_l	±0.002
C_n	±0.003
C_Y	±0.006
M_∞	±0.02
α, deg	±0.1
β, deg	±0.1
δ_r, deg	±0.1
i_v, deg	±0.1

No corrections due to tunnel-wall effects or sting interference have been applied to the data. It is believed that these corrections would be small. (See refs. 3 and 4.)

RESULTS AND DISCUSSION

The effects of deflection or removal of the vertical tails on the model normal force and pitching-moment characteristics at Mach numbers of about 0.93 and 0.62 are shown in figures 2 and 3, respectively. (The results shown at a Mach number of 0.92 for a vertical-tail deflection of 8.1° were obtained from ref. 1.) Summary curves showing the effect of vertical-tail deflection and Mach number on the variation of longitudinal center-of-pressure location and longitudinal stability parameter with normal-force coefficient are presented in figures 4 and 5, respectively. Figure 6 (based on results at angles of sideslip of 0° and about 5°) shows the effect of Mach number on the lateral stability derivatives for the configuration with approximately 0° tail incidence and also the effect of removing the vertical tails at a Mach number of about 0.93.

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The effects of rudder deflection on the lateral aerodynamic characteristics at a Mach number of about 0.94 are shown for angles of sideslip of 0° and about 5° (maximum deviation from 5° was about $\pm 0.1^{\circ}$) in figures 7 and 8, respectively. Figure 9 shows the effect of angle of sideslip on the yawing-moment and side-force coefficients due to rudder deflection for a Mach number of about 0.94.

Effect of Vertical-Tail Deflection on Longitudinal Aerodynamic Characteristics

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Normal-force characteristics.- Without the vertical tails on the model the normal-force curves are nonlinear at both Mach numbers of 0.94 and 0.63. (See figs. 2 and 3.) At low angles of attack the slopes correspond closely to linear-theory predictions. At moderate angles of attack the slopes increased. These increases are typical for low-aspect-ratio wings at both subsonic and transonic speeds (for example, see ref. 5) and are associated with viscous effects on the wing upper surface. Reference 1 compares a method for predicting the nonlinear effects (see ref. 6) with experimental results at a Mach number of about 0.94 on models somewhat similar to the one of the present investigation. The method showed fair agreement in slope with the experimental normal-force curve slopes.

Similar to the results of reference 1, figures 2 and 3 show that adding the vertical tails to the model increased both the linearity and the slope of the normal-force curves. These changes are associated with the end-plate effects of the vertical tails; that is, the tails increased the model effective aspect ratio. Tail deflection had considerable influence on the magnitude of normal-force coefficient at both Mach numbers. The toed-in deflection of 8.1° resulted in increases in normal-force coefficients compared with the tail-off condition; whereas, the toed-out deflection of -5.0° (tested only at a Mach number of 0.93) caused decreases and the approximately 0° deflection had little effect on normal-force coefficient. These changes are associated with the vertical tails causing lower pressures for toed-in deflection or higher pressures for the toed-out deflection over the upper surface of the outboard wing sections.

Pitching-moment characteristics.- The changes in normal force due to the addition of the tails or tail deflection are also reflected in the pitching-moment characteristics. (See figs. 2(b), 2(c), 3(b), 3(c), 4, and 5.) For example, the pressure changes on the wing which are due to tail deflection had large effects on the pitching-moment coefficients. Changing tail deflection from 8.1° to about 0° or to -5° (tested only at a Mach number of 0.93) caused the low-lift pitching-moment coefficients to change from large negative values to near zero or positive values. These changes are desirable, of course, since they would result in decreases in trim drag.

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At a Mach number of about 0.93 (see fig. 2(b)) changing the tail deflection from 8.1° to -0.1° or -5.0° decreased or eliminated the pitch-up tendency, respectively, at moderate angles of attack. At the highest angles, the curves for the different tail deflection configurations tend to approach each other. These effects at the moderate and higher angles of attack are probably associated with a leading-edge-separation vortex-type flow and shocks (for example, see ref. 7) that had an increasingly predominant influence on the outboard upper surface flow as the angle of attack was increased. That is, the outboard-flow separation caused by the vortex-type flow and shocks at the higher angles tends to reduce the
L effect of the vertical tails on the wing pressures. This tendency would
7 be most pronounced for a tail deflection of 8.1° where the low outboard
4 wing pressures caused by the tails would tend to be conducive to outboard
6 flow separation.

At a Mach number of about 0.62, relative changes in the pitching-moment coefficient with angle of attack (see fig. 3(b)) for the different configurations are not as large as they were at a Mach number of about 0.93 (see fig. 2(b)). The changes at the lower Mach number are probably smaller because flow separation has been delayed to higher angles of attack. Either no shocks or only relatively weak shocks which would tend to induce flow separation existed at a Mach number of about 0.62. All the configurations had slight pitchup tendencies at the lower speed as shown in figures 3(b) and 3(c) and also figure 5 for the two tail-on configurations.

Effect of Mach Number on Lateral Stability Derivatives

The results of figure 6, which are based on tests at angles of sideslip of 0° and about 5°, show that at a Mach number of 0.93 the configuration with the tails deflected -0.1° had a small amount of directional stability at all angles of attack investigated and positive effective dihedral over most of the angle range. Removing the tails caused the model to become directionally unstable and decreased the positive effective dihedral at a Mach number of 0.94. At a Mach number of 0.63 the model with tails deflected -0.1° had essentially neutral directional stability and effective dihedral.

Effect of Rudder Deflection on Lateral Aerodynamic Characteristics

The results in figures 7 and 8 show that rudder deflection had practically no effect on rolling-moment coefficient. Figure 9, which summarizes the effects of rudder deflection on yawing-moment and side-force coefficients, shows that these coefficients varied almost linearly with

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rudder deflection. It also shows that angles of sideslip up to about 5° had no or very little effect on the rudder effectiveness. The effect of angle of attack in the range investigated on rudder effectiveness was also small.

CONCLUSIONS

A wind-tunnel investigation has been made to study the effects of vertical tail (at Mach numbers of about 0.62 and 0.93) and rudder deflection (at a Mach number of 0.94) on the aerodynamic characteristics of a hypersonic glider model. The model had a highly swept clipped-tip low triangular wing. It was tested with and without upper surface wing-tip vertical tails and with various deflections of single split-type rudders which were mounted on the tail outer surfaces. Vertical-tail deflection was varied from 8.1° toe-in to a maximum of 5.0° toe-out and outward rudder deflection was varied from 0° to 21.1°. Results of the investigation which were obtained at angles of attack from -2° to 19° and angles of sideslip of 0° and about 5° indicate the following:

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1. Adding the vertical tails to the model caused increases in both the linearity and the slope of the normal-force curves.

2. Changing vertical-tail deflection from 8.1° toe-in to 5° toe-out at a Mach number of about 0.93 shifted zero-lift pitching moment from a large negative value to a positive value and eliminated the pitchup tendency at moderate angles of attack.

3. Although changing vertical-tail deflection from 8.1° toe-in to about 0° at a Mach number of 0.62 decreased the negative zero-lift pitching moment, it did not eliminate the pitchup tendency.

4. At a Mach number of 0.93 the model with tails on had a small amount of directional stability at all angles of attack and positive effective dihedral over most of the angle range. At a Mach number of 0.63 this model had essentially neutral directional stability and effective dihedral.

5. Rudder deflection had essentially no effect on rolling moment. Both yawing moment and side force varied almost linearly with rudder deflection. Angles of sideslip up to about 5° and angle of attack had very little effect on rudder effectiveness.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., August 18, 1959.

[redacted]

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1. West, F. E., Jr., Trescot, Charles D., Jr., and Wiley, Alfred N., Jr.: Aerodynamic Characteristics for Two Hypersonic Glider Models With and Without Wing and Vertical-Tail Trailing-Edge Chord-Extensions at a Mach Number of 0.94. NASA TM X-66, 1959.

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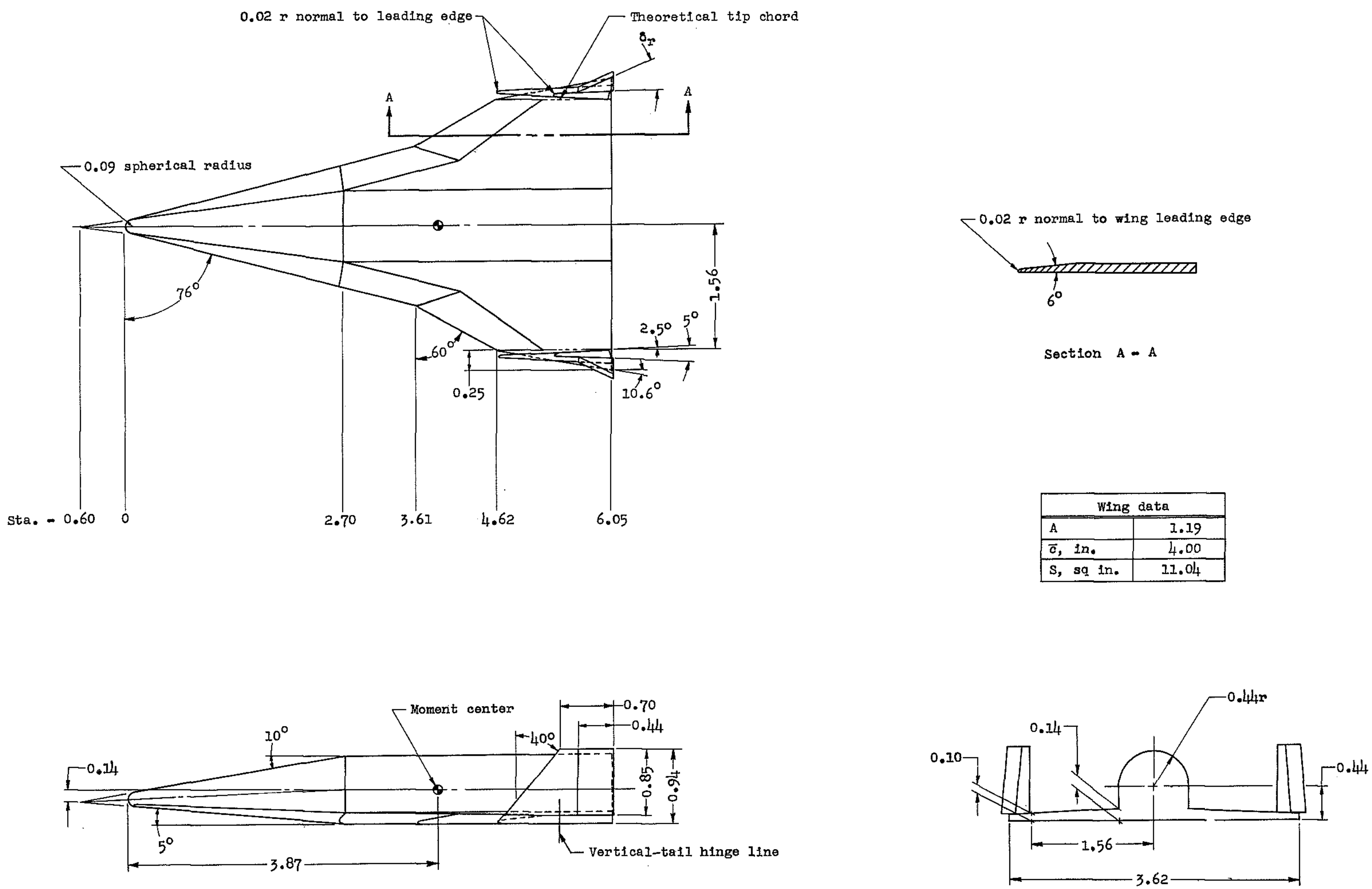
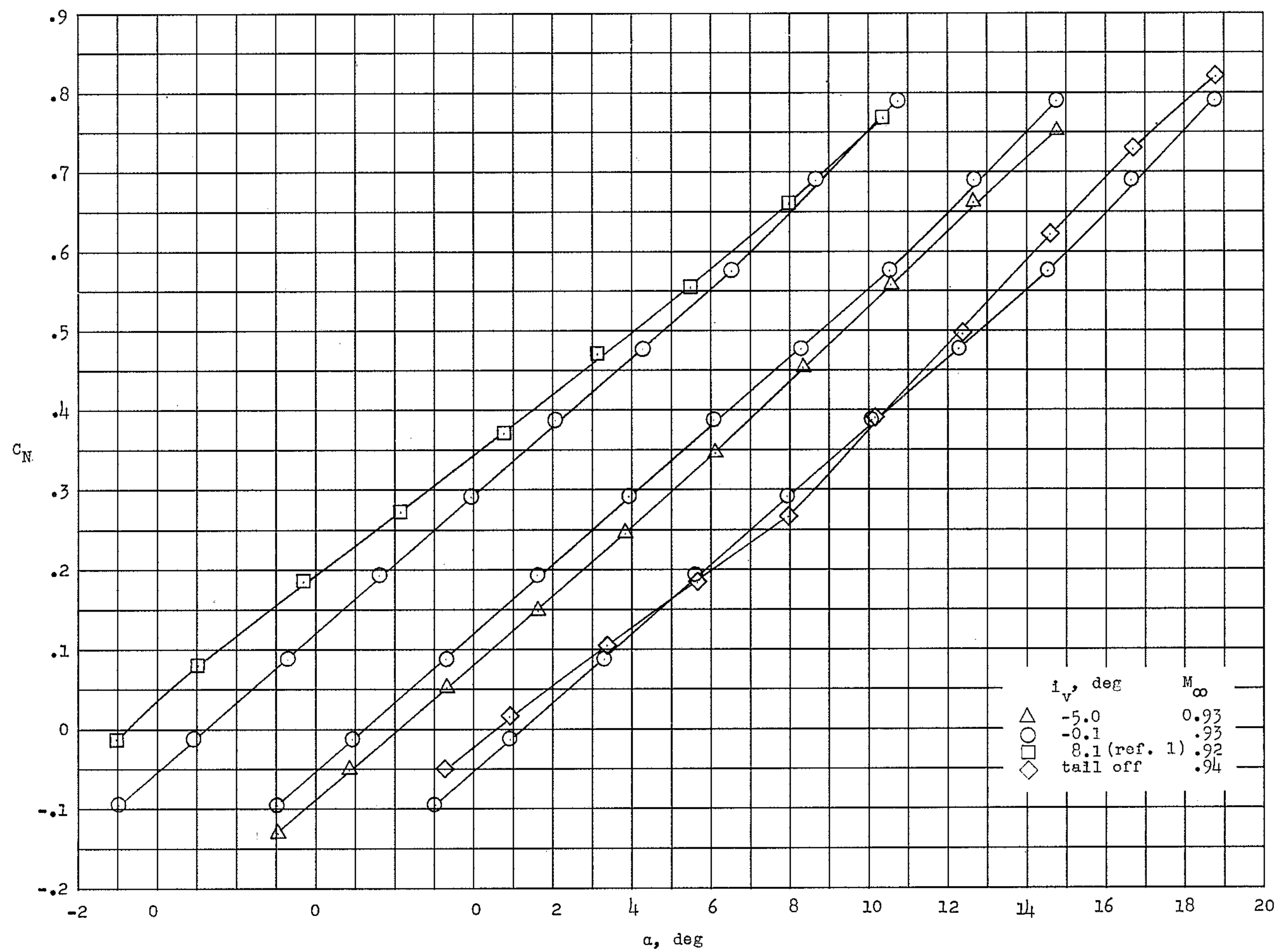
6. Flax, A. H., and Lawrence, H. R.: The Aerodynamics of Low-Aspect-Ratio Wings and Wing-Body Combinations. Rep. No. CAL-37, Cornell Aero. Lab., Inc., Sept. 1951.

7. West, F. E., Jr., and Henderson, James H.: Relationship of Flow Over a 45° Sweptback Wing With and Without Leading-Edge Chord-Extensions to Longitudinal Stability Characteristics at Mach Numbers From 0.60 to 1.03. NACA RM L53H18b, 1953.



Wing data	
A	1.19
$\bar{c}$, in.	4.00
S, sq in.	11.04

Figure 1.- Drawing of model $B_1W_4V_1$. (All dimensions are in inches unless otherwise indicated.)



(a) Variation of C_N with α.

Figure 2.- Effect of vertical tail and vertical-tail incidence on the longitudinal aerodynamic characteristics at a Mach number of about 0.93. $\beta = 0^\circ$; $\delta_r = 0^\circ$.

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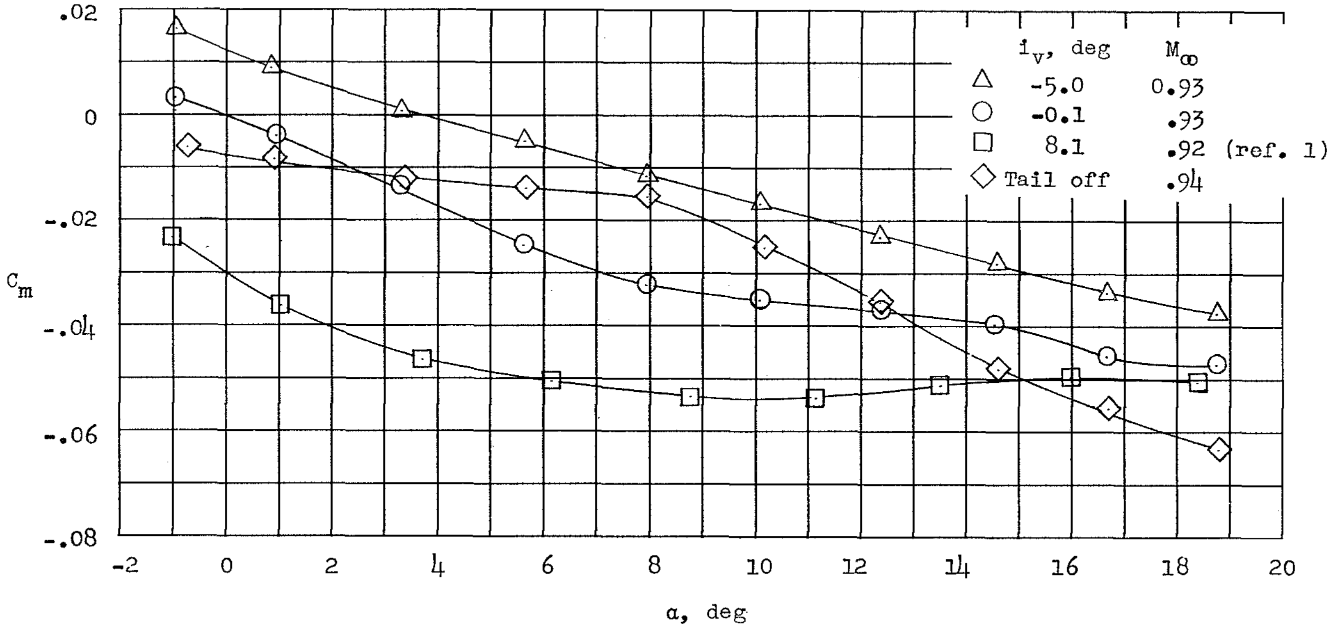
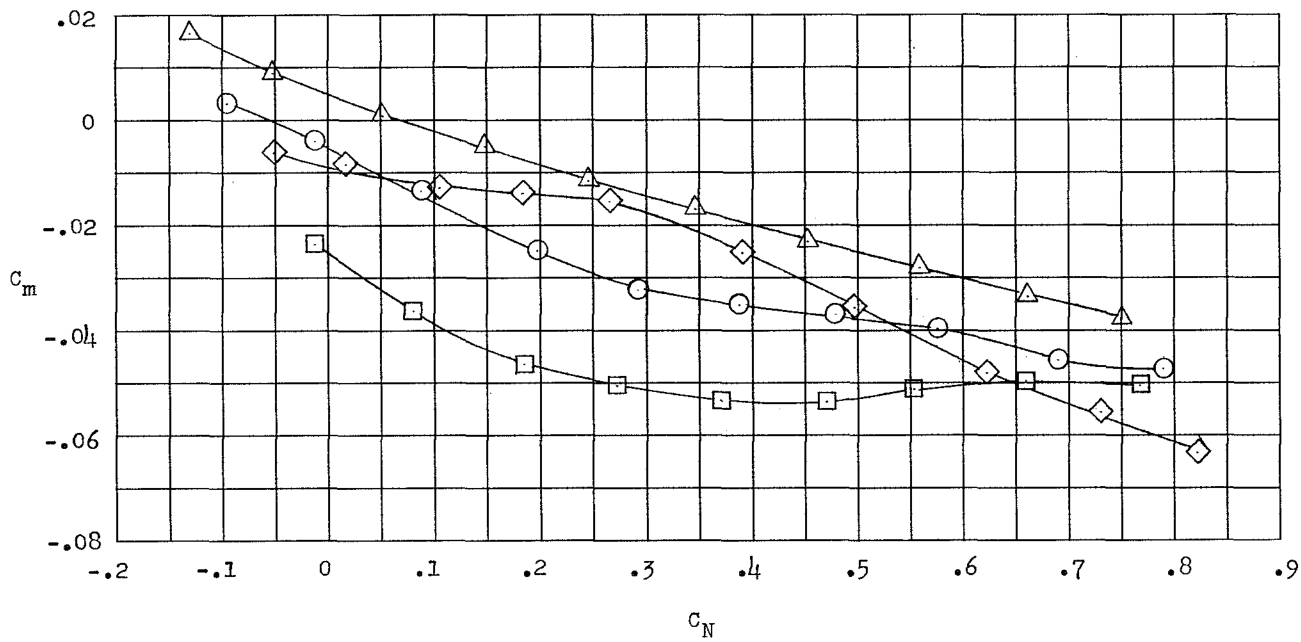


(b) Variation of C_m with α.



(c) Variation of C_m with C_N.

Figure 2.- Concluded.

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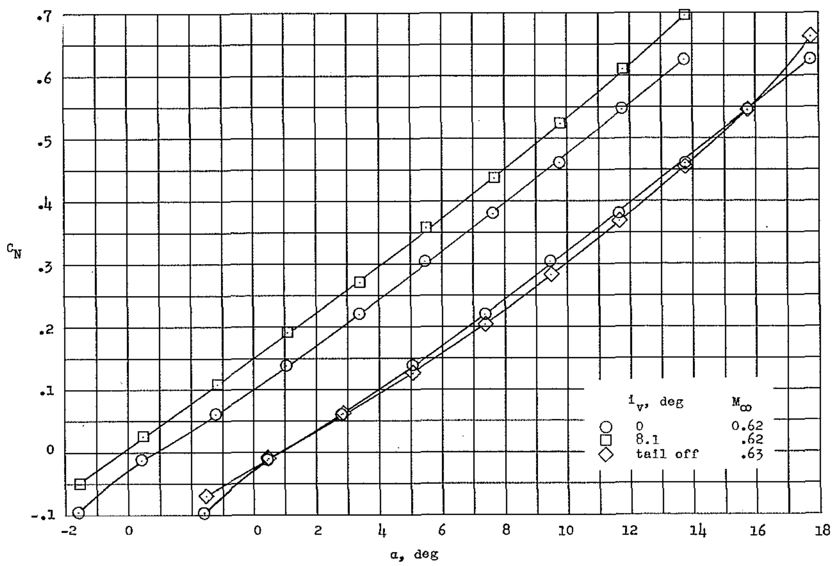
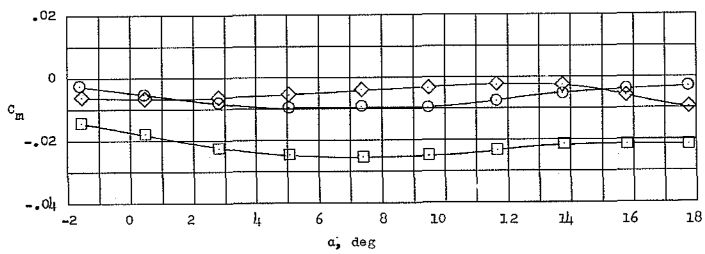
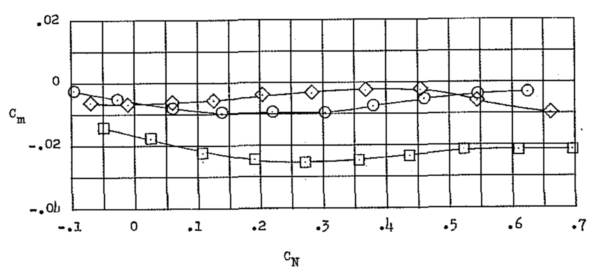


(a) Variation of C_N with α.



(b) Variation of C_m with α.



(c) Variation of C_m with C_N.

Figure 3.- Effect of vertical tail and vertical-tail incidence on the longitudinal aerodynamic characteristics at a Mach number of 0.62. $\beta = 0^o$; $\delta_r = 0^o$.

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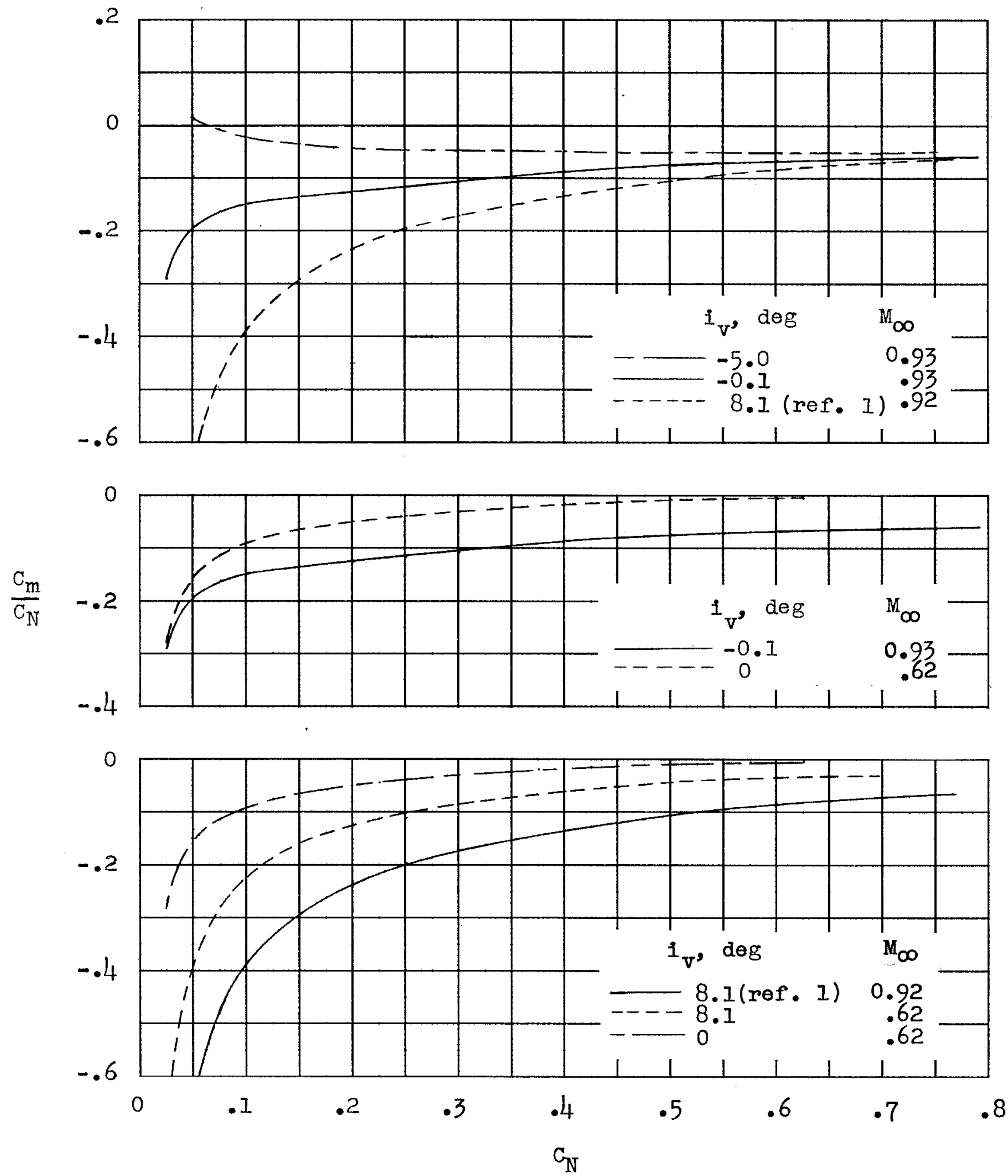

Figure 4.- Effect of vertical-tail incidence and Mach number on the longitudinal center-of-pressure location. $\beta = 0^{\circ}$; $\delta_r = 0^{\circ}$.

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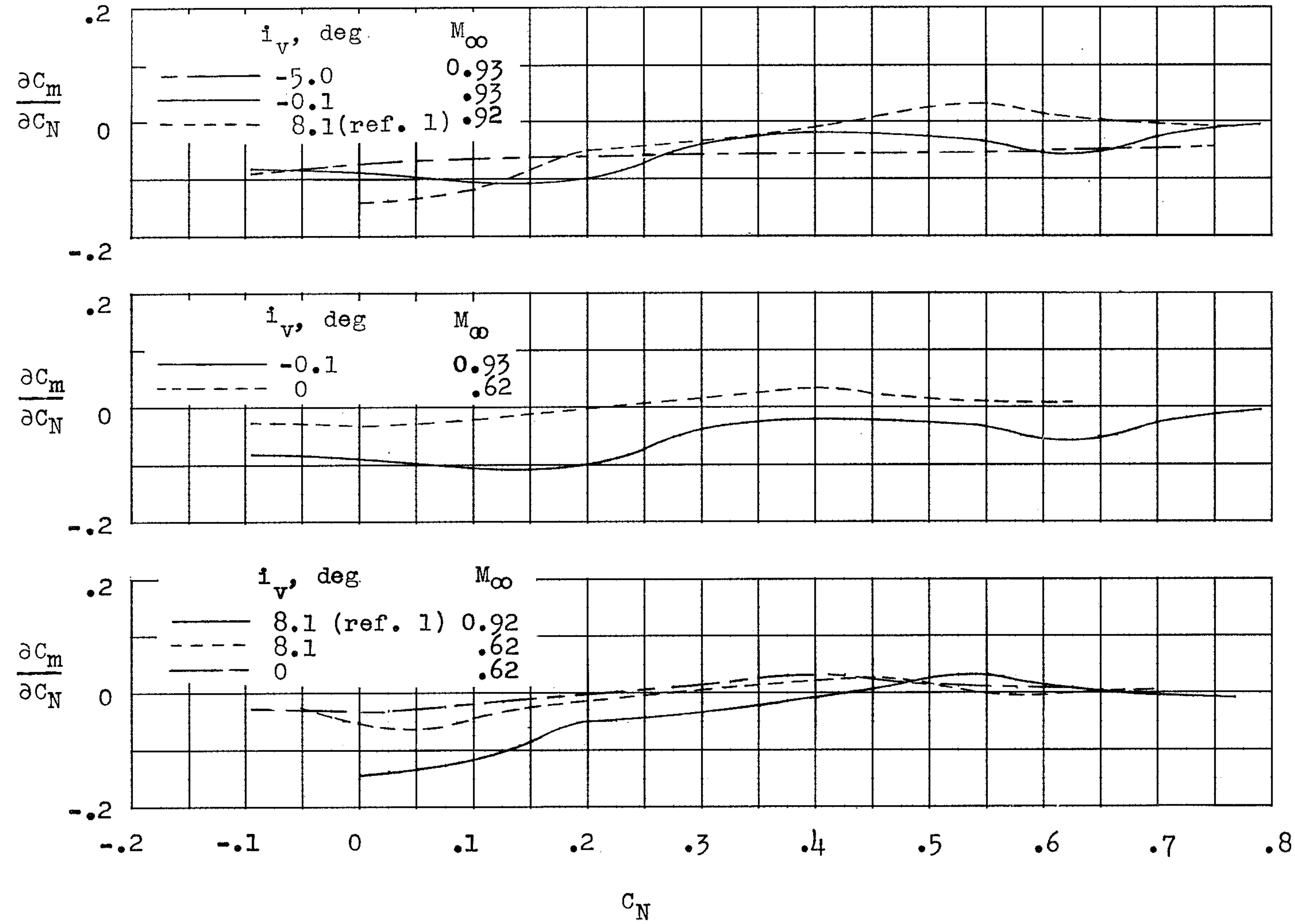

Figure 5.- Effect of vertical-tail incidence and Mach number on the longitudinal stability parameter. $\beta = 0^{o}$; $\delta_r = 0^{o}$.

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[redacted]

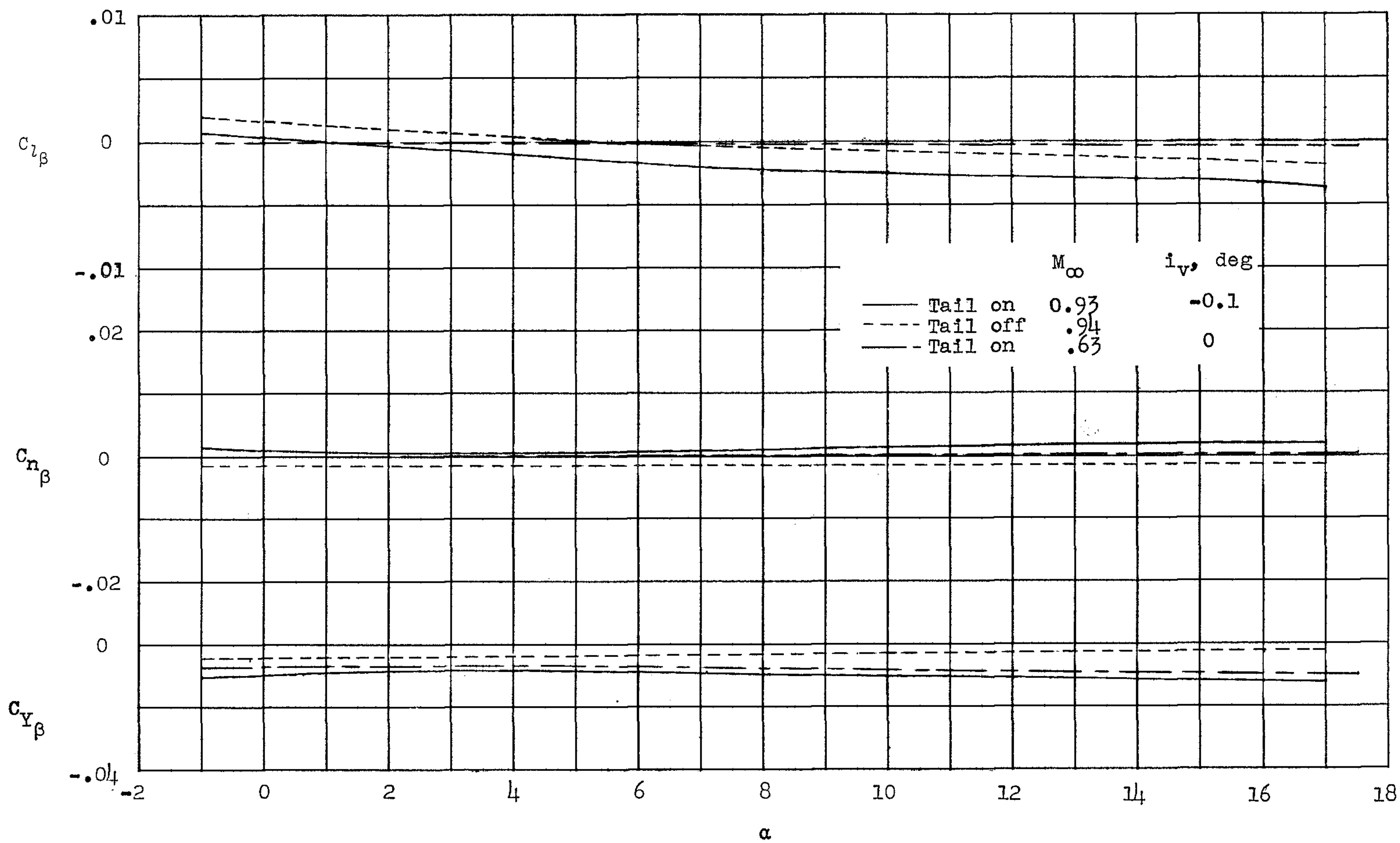

Figure 6.- Effect of Mach number on lateral stability derivatives due to sideslip. $\delta_r = 0^\circ$.

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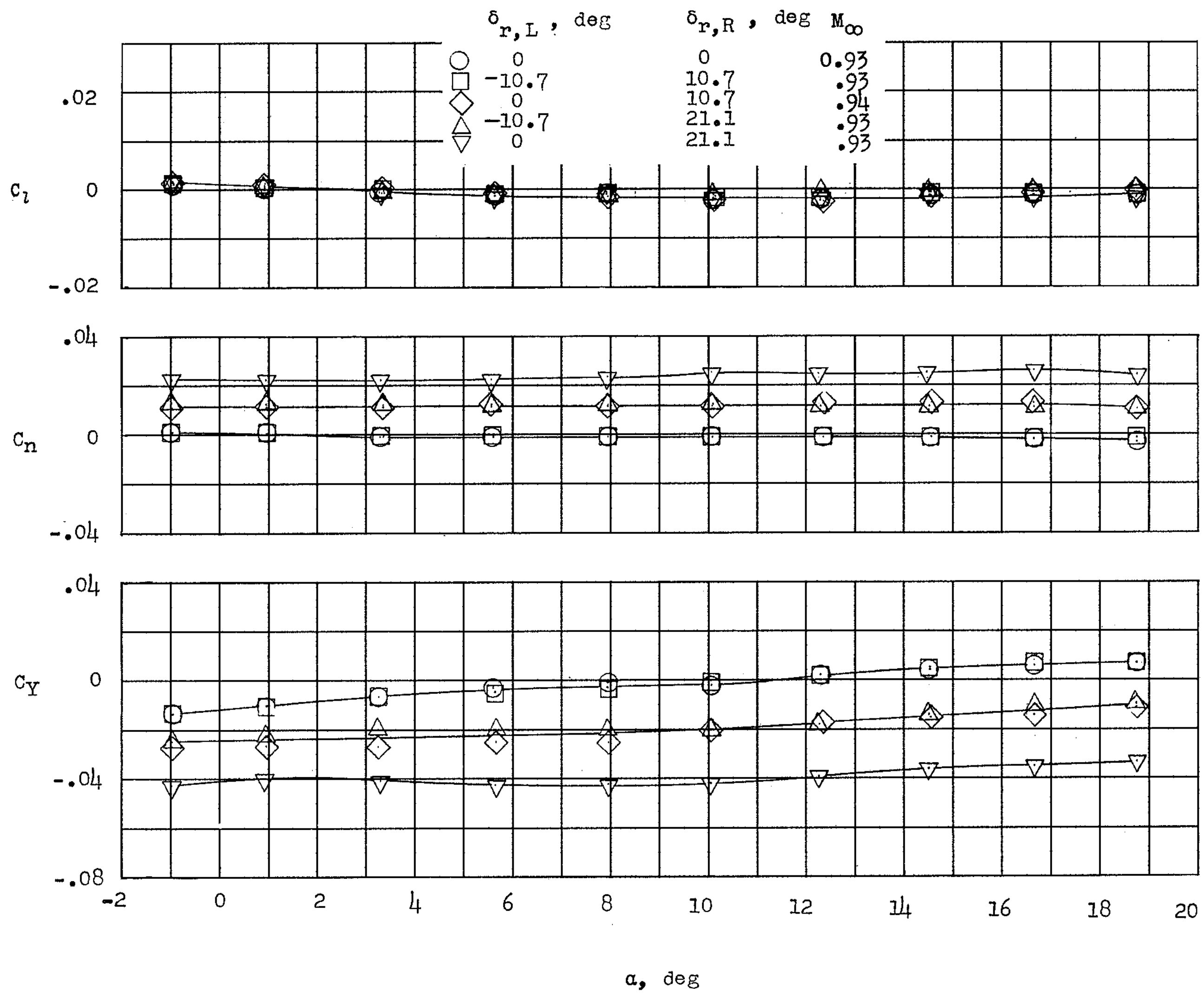

Figure 7.- Effect of rudder deflection on the lateral aerodynamic characteristics at a sideslip angle of 0°. $M_\infty \approx 0.93$; $i_v = -0.1^{\circ}$.

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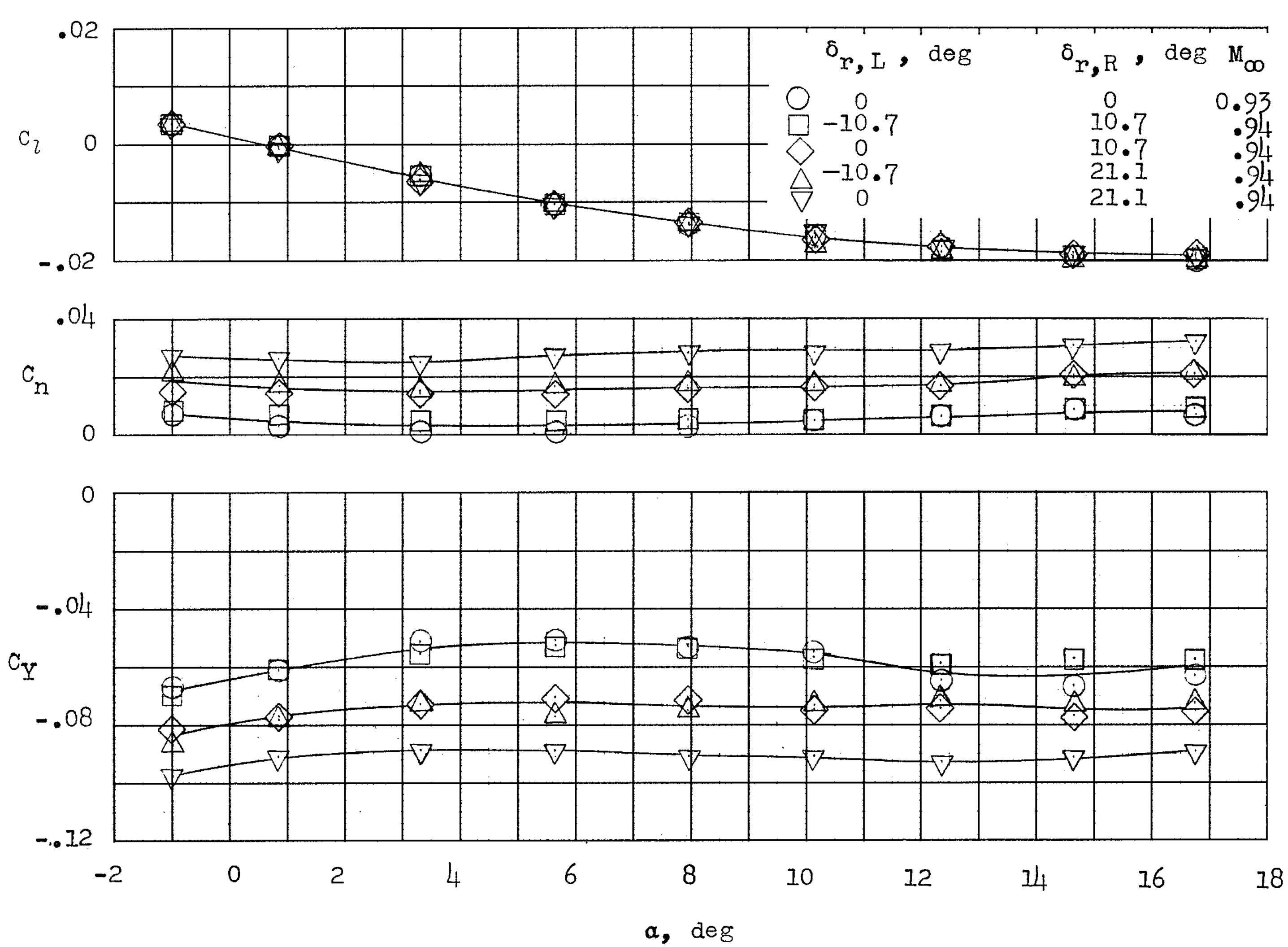
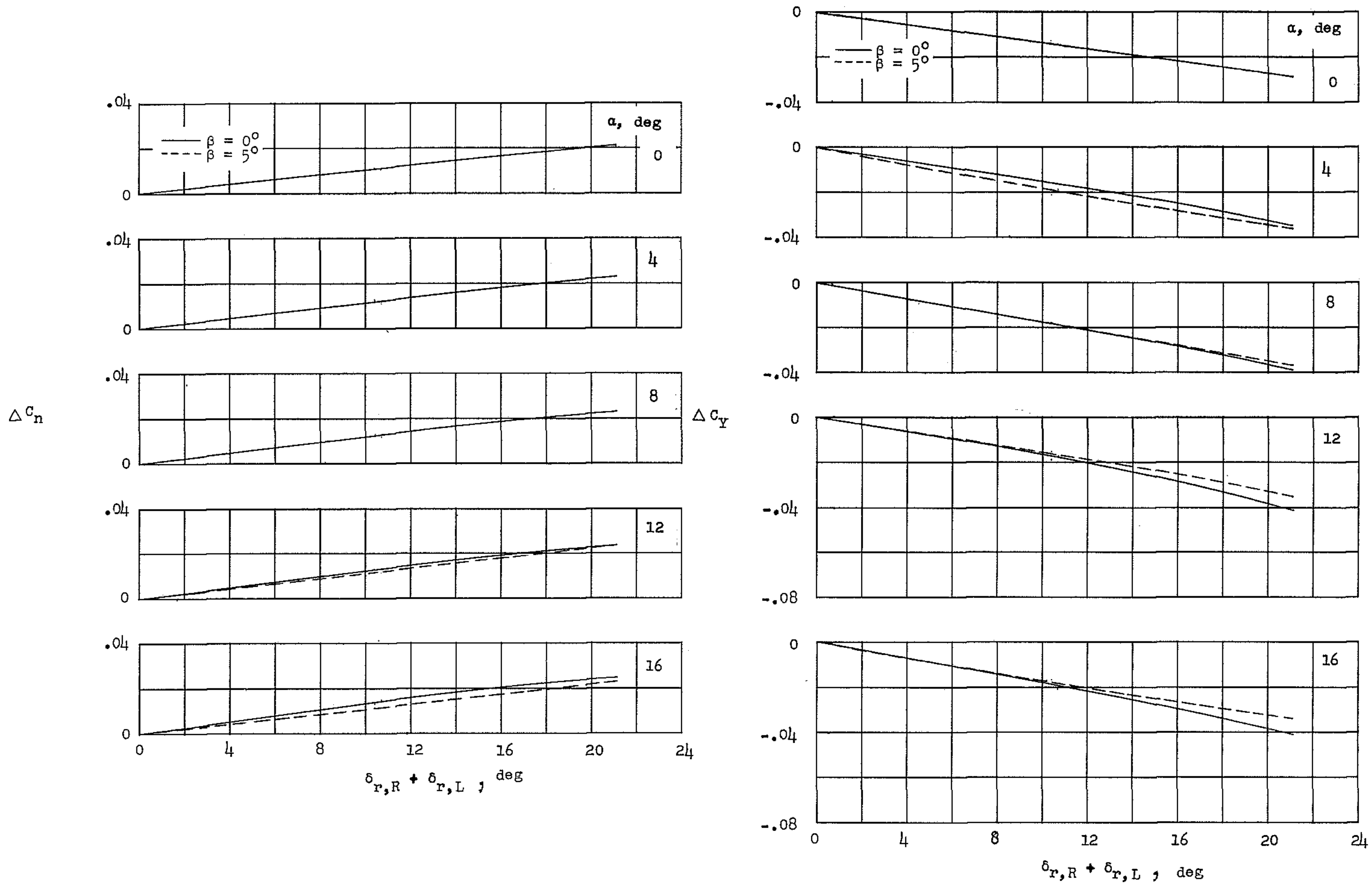


Figure 8.- Effect of rudder deflection on the lateral aerodynamic characteristics at a sideslip angle of approximately 5.0°. $M_\infty \approx 0.94$; $i_V = -0.1°$.



(a) Variation of C_n with $\delta_{r,R} + \delta_{r,L}$.

(b) Variation of C_Y with $\delta_{r,R} + \delta_{r,L}$.

Figure 9.- Lateral aerodynamic characteristics due to rudder deflection at angles of sideslip of 0° and 5°. $M_{\infty} \approx 0.94$; $i_V = -0.1^{\circ}$.